

Amendments to the Claims:

This listing of claims will replace all prior versions, and listings, of claims in the application:

Listing of Claims:

1. (Currently Amended) A haptic interface device to provide haptic interaction to a user manipulating a tool, the haptic interface device comprising:
 - an attachment point;
 - a first, a second, a third, and a fourth cable, each having a first and a second end, and each coupled at respective first ends to the attachment point;
 - a first tool translation effector device having a first cable guide, a second tool translation effector device having a second cable guide, a third tool translation effector device having a third cable guide, and a fourth tool translation effector device having a fourth cable guide, the first, the second, the third and the fourth cable guide positioned, relative to each other, such that each of the first, the second, the third, and the fourth ~~tool translation effector devices~~ cable guides occupies a vertex of a tetrahedron, each tool translation effector device having coupled thereto the second end of a respective one of the first, the second, the third, and the fourth cables such that, as the attachment point moves, each of the first, the second, the third, and the fourth cables is retracted or paid out accordingly by the respective tool translation effector device, each tool translation effector device including controlling means for selectively varying an active tension on the respective cable;
 - metering means for metering each of the first, the second, the third, and the fourth cables as they are retracted and paid out; and
 - calculating means for calculating a force response vector to be applied to the attachment point at least in part on the basis of a position of the attachment point, as determined by a distance between each of the first, the second, the third, and the fourth ~~tool translation effector devices~~ cable guides and the attachment point, the calculating means is configured to calculate the force response vector according to the equation $J = (At - f) + a[\tau]^2$ by adjusting τ

such that J is close to or equal to zero, where τ is a scalar representing magnitudes of force to be applied to the first, the second, the third, and the fourth cables, $A\tau$ is the force response vector to be applied to the attachment point, f is a target force vector, and α is a stability coefficient.

2. (Previously Presented) The haptic interface device of claim 1 wherein:

the controlling means of each of the first, the second, the third, and the fourth tool translation effector devices includes a spool and a motor coupled to rotatably drive the spool, the motor and spool selectively operable to wind and unwind the second end of the respective cable; and

the metering means includes:

counting means for counting fractions of rotations of the spool of each of the first, the second, the third, and the fourth tool translation effector devices; and

compensating means for compensating for a change in ratio between changes in distance from each tool translation effector device to the attachment point and angular rotation of the respective spool.

3. (Previously Presented) The haptic interface device of claim 57 wherein

the establishing means includes a controller configured to direct the first tool translation effector device to retract, during an initialization procedure, the first cable until the attachment point is at a selected position relative to the first tool translation effector device.

4. (Previously Presented) The haptic interface device of claim 58 wherein

the establishing means includes respective brakes configured to lock each of the first, the second, the third, and the fourth tool translation effector devices when electric current is removed therefrom, and a memory configured to receive and store, after current is removed from the brakes and prior to a complete shutdown of the device, the respective distances between each of the first, the second, the third, and the fourth tool translation effector devices and the attachment point, and to provide the stored distances during a startup procedure.

5. (Previously Presented) The haptic interface device of claim 57 wherein the establishing means includes a sensor configured to sense, independent of the first tool translation effector device, a position of the attachment point relative to the first tool translation effector device.

6. (Original) The haptic interface device of claim 5 wherein the establishing means includes means for reestablishing the distance from time to time during operation.

7. (Previously Presented) The haptic interface device of claim 1, further comprising:
a sensor array at the attachment point configured to provide signals corresponding to an orientation of the attachment point.

8. (Original) The haptic interface device of claim 7 wherein the sensor array is configured to provide signals corresponding to roll, pitch, and yaw of the attachment point.

9. (Currently Amended) A haptic interface device to provide haptic interaction to a user manipulating a tool, the haptic interface device comprising:
an attachment point configured to receive the tool and to be moved at least within an n-dimensional workspace, in which "n" has a value of two (2) or three (3);
a plurality of not more than four cables and a plurality of not more than four cable guides, each cable coupled at a respective first end to the attachment point and extending to a respective cable guide of the plurality of cable guides, and wherein the n-dimensional workspace is defined by $n+1$ cable guides of the plurality of cable guides;
a processor system configured to calculate a respective tension vector for each respective cable based at least on a mathematical optimization of an equation having at least a first term and a second term, the first term corresponding to a net vector having at least a calculated force response vector and the respective tension vectors for the respective cables as components thereof, the second term corresponding to a function with at least a respective

magnitude of each of the respective tension vectors as arguments thereof, wherein the mathematically optimized equation is close to or equal to zero; and

a plurality of tool translation effector devices communicatively coupled to the processor system, each having coupled thereto a second end of a respective one of the plurality of cables such that, as the attachment point moves relative to that tool translation effector device, the cable coupled thereto is retracted or paid out accordingly, each tool translation effector device configured to selectively vary an active tension on the cable coupled thereto based at least on the calculated respective tension for the respective cable and to meter the cable as it is retracted and paid out.

10-11. (Canceled)

12. (Currently Amended) A haptic device for operation by a user, comprising:
a user interface tool configured to be manipulated by the user and moved within a volume of space, and including a sensor array configured to detect at least one of roll, pitch, and yaw of the user interface tool;

a first, a second, a third, and a fourth tool translation effector device, each tool translation effector device including a respective cable guide component coupled to a support structure in positions such that the first, second, third, and fourth tool translation effector devices respective cable guide components define between them a tetrahedron within the volume of space, each of the tool translation effector devices further including a respective spool, a respective motor, and a respective encoder configured to provide a signal corresponding to rotation of the respective spool; and

a first, a second, a third, and a fourth cable each having a respective first and a respective second end, the first end of each of the first, the second, the third, and the fourth cables coupled to the user interface tool and the second end of each of the first, the second, the third, and the fourth cables wound and unwound on the spool of a respective one of the tool translation effector devices, each of the motors operable to drive the respective spool to selectively apply active tension to the respective cable; and

a processor system coupled to the first, the second, the third, and the fourth tool translation effector devices being configured to calculate tension vectors corresponding to active tensions applied to the respective cables based at least on a mathematical optimization of a mathematical equation having at least a first term and a second term, the first term including a net vector having a calculated force vector and the calculated tension vectors as components thereof, and the second term including a function having a respective magnitude of each of the calculated tension vectors as arguments thereof, wherein the mathematically optimized equation is close to or equal to zero, and wherein the active tensions applied to the respective cables yield an actual force vector applied to the user interface tool that corresponds to the calculated force vector.

13. (Currently Amended) The haptic device of claim ~~74~~⁴² wherein the sensor array is configured to detect roll, pitch, and yaw of the user interface tool.

14. (Currently Amended) The haptic device of claim 12, ~~further comprising a wherein the processor system coupled to receive~~ receives the signals from the respective encoders, the processor system configured to determine movement of the user interface tool therefrom, to ~~determine a calculate the force vector to be applied to the user interface tool, and to determine an amount of active tension to be applied by the motor of each of the tool translation effector devices to produce the determined force vector based at least on a position of the user interface tool.~~

15. (Previously Presented) The haptic device of claim 14 wherein the processor system is configured to compensate for changes in effective diameter of the spools of the first, the second, the third, and the fourth tool translation effector devices due to changing thickness of cable on each of the spools as the respective cable is wound and unwound from the respective spool.

16. (Canceled)

17. (Previously Presented) The haptic device of claim 12 wherein the processor system is configured to establish an initial position of the tool by retracting, in turn, each of the first, the second, the third, and the fourth cables to a known length position.

18. (Previously Presented) A haptic device for operation by a user, comprising:

- a support structure;

- a port coupled to the support structure;

- a user interface tool configured to be manipulated by the user and moved within a volume of space, the user interface tool includes a tool shaft having a first and a second end, the tool shaft passing through the port such that the tool shaft pivots at the port and manipulation of the second end of the tool shaft is reflected in movement of the first end of the tool shaft;

- a first, a second, a third, and a fourth tool translation effector device, each coupled to the support structure in positions such that the first, the second, the third, and the fourth tool translation effector devices define between them a tetrahedron within the volume of space, each of the tool translation effector devices including a respective spool and a respective encoder configured to provide a signal corresponding to rotation of the respective spool; and

- a first, a second, a third, and a fourth cable each having a respective first and a respective second end, the first end of each of the first, the second, the third, and the fourth cables coupled to the first end of the tool shaft and the second end of each of the first, the second, the third, and the fourth cables wound and unwound on the spool of a respective one of the tool translation effector devices.

19. (Previously Presented) The haptic device of claim 18, further comprising:

- a first sensor located at the port and coupled to the tool shaft, and configured to detect rotation of the user interface tool around an axis.

20. (Previously Presented) The haptic device of claim 18, further comprising:
a first sensor configured to detect rotation of the user interface tool around an axis, and a second sensor coupled to the second end of the tool shaft and configured to detect gripping force exerted by the user.

21. (Original) The haptic device of claim 18 wherein the second end of the tool shaft is configured to provide for the user a simulation of a selected tool.

22. (Original) The haptic device of claim 21 wherein the selected tool is formed as one of a stylus, a pen, a pliers, a wrench, a forceps, a scalpel, an endoscope, or an arthroscope.

23. (Original) The haptic device of claim 18, further comprising:
a feedback device coupled to the tool shaft and configured to selectively apply rotational force to the tool shaft.

24. (Original) The haptic device of claim 23 wherein the feedback device is located at the port.

25. (Original) The haptic device of claim 18, further comprising:
a feedback device coupled to the second end of the tool shaft and configured to selectively resist gripping force exerted by the user.

26. (Currently Amended) The haptic device of claim 14 wherein the processor system is configured to maintain a virtual environment within which the user interface tool is operated, and to apply the actual force vector as feedback from the virtual environment to the user interface tool.

27. (Currently Amended) The haptic device of claim ~~44~~ 12, further comprising:
a remote tool, and wherein the processor system is configured to control operation of the remote tool in accordance with the movement and orientation of the user interface tool.

28. (Currently Amended) The haptic device of claim 27 wherein the processor system is configured to apply the actual force vector as feedback from the remote tool to the user interface tool.

29. (Previously Presented) A method, comprising:
applying a selectively variable active tension to each of a plurality of cables having respective first and second ends, each of the plurality of cables coupled at its respective first end to a tool, and at its respective second end to a respective anchor point;
measuring a change of cable length between the tool and each respective anchor point;
establishing an initial length of cable between the tool and each of the anchor points;
locking, during a shutdown procedure, each of the plurality of cables at the respective anchor point;
storing, after the locking and before completing the shutdown procedure, a value indicative of a known length of each of the cables in a memory; and
recovering the value indicative of the known length of each of the cables from the memory during a startup procedure.

30. (Original) The method of claim 29 wherein establishing an initial length of cable comprises moving the tool in turn to each of the anchor points such that the length of cable between the tool and the respective anchor point is effectively zero.

31-32. (Canceled)

33. (Previously Presented) The method of claim 29 wherein establishing an initial length of cable comprises:

- tracking a position of the tool independent of the measuring; and
- correlating the position of the tool with known positions of the anchor points.

34-37. (Canceled)

38. (Currently Amended) A method, comprising:

selectively applying active tension to each of four cables, each cable having a first end coupled to a tool and having a ~~second end coupled~~ length extending from the first end to a respective vertex of a tetrahedron such that, as the tool is moved closer to any respective vertex of the ~~vertices tetrahedron~~, the respective ~~cables are~~ length of cable extending from the ~~respective first end to the respective vertex is drawn in at the respective vertices~~, thereby ~~shortening decreasing the~~ respective length of the ~~respective cables~~ cable, and as the tool is moved away from any respective vertex of the ~~vertices tetrahedron~~, the respective ~~cables are~~ length of cable extending from the respective first end to the respective vertex is fed out from the ~~respective vertices~~, thereby ~~lengthening increasing the~~ respective length of the ~~respective cables~~ cable;

tracking changes in length of each of the four cables; and

deriving a change of position of the tool on the basis of tracked changes in length of each of the four cables; and

optimizing, to be close to zero, an equation having at least a first term and a second term, the first term including a net vector having as components thereof a selected force vector that corresponds to an actual response feedback force vector applied to the tool and calculated target tension vectors corresponding to active tensions applied to each of the four cables, and second term including at least a function having at least magnitudes of the calculated target tension vectors as arguments thereof.

39. (Previously Presented) The method of claim 38, comprising measuring rotation of the tool about one or more of three mutually perpendicular axes.

40-41. (Canceled)

42. (Previously Presented) The haptic device of claim 13, further comprising a processor system coupled to receive information from the sensor array and coupled to receive the signals from the respective encoders, the processor system configured to determine movement and orientation of the tool therefrom.

43-48. (Canceled)

49. (Currently Amended) The haptic interface device of claim 9 wherein the plurality of tool translation effector devices includes at least a first, a second, a third, and a fourth tool translation effector device, each of the plurality of first, the second, the third, and the fourth tool translation effector devices is having a respective cable guide of the plurality of cable guides, and where the respective cable guides are positioned relative to each other such that each tool translation effector devices-respective cable guide occupies a vertex of a tetrahedron.

50. (Previously Presented) The haptic interface device of claim 9 wherein each of the plurality of tool translation effector devices includes a brake configured to lock the respective tool translation effector device while the haptic interface device is powered down.

51. (Previously Presented) The haptic interface device of claim 9, further comprising:
establishing means for establishing, during an initialization procedure, a distance between each of the tool translation effector devices and the attachment point.

52. (Previously Presented) The haptic interface device of claim 59 wherein the sensor array is configured to provide signals corresponding to each of a roll, a pitch, and a yaw of the tool.

53. (Previously Presented) The haptic device of claim 12 further comprising:
a first, a second, a third, and a fourth brake coupled to respective ones of the first, the second, the third, and the fourth tool translation effector devices and configured, when engaged, to prevent rotation of the spools associated with the respective tool translation effector devices.

54. (Previously Presented) The haptic device of claim 12 wherein the device comprises no more than four cables.

55. (Previously Presented) The method of claim 62, comprising:
locking, during a shutdown procedure, each of the plurality of cables at the respective anchor point;
storing a value indicative of a known length of each of the cables in a memory;
and
recovering the value indicative of the known length of each of the cables from the memory during a startup procedure

56. (Canceled)

57. (Currently Amended) The haptic interface device of claim 1, comprising establishing means for establishing a respective distance between each of the first, the second, the third, and the fourth ~~tool translation effector devices~~ cable guides and the attachment point.

58. (Currently Amended) The haptic interface device of claim 57 wherein the establishing means comprises a calibration point at which the attachment point can be positioned,

and from which the respective distances between each of the first, the second, the third, and the fourth ~~tool translation effecter devices~~ cable guides and the attachment point are known.

59. (Previously Presented) The haptic interface device of claim 9, comprising a sensor array associated with the attachment point and configured to provide signals corresponding to at least one of roll, pitch, and yaw of the tool.

60. (Currently Amended) The method of claim 38, comprising establishing ~~a~~ the respective length of each of the four cables by positioning the tool at a calibration point from which the respective lengths of each of the four cables is known.

61. (Currently Amended) The method of claim 38, comprising selecting a value of active tension applied to each of the four cables on the basis of ~~a~~ the selected force vector that corresponds to the actual response feedback force vector to be applied to the tool.

62. (Currently Amended) A method of operating a haptic device having a tool coupled to a first end of a first cable, comprising:

~~selectively applying active tension to a cable having a first end and a second end;~~
~~the first end of the cable coupled to a tool and the second end of the cable coupled to an anchor point;~~

~~as the a tool is moved closer to the anchor point in a first direction, winding the a~~
first cable having a first end coupled to the tool onto a spool;

~~as the tool is moved away from the anchor point in a second direction which is~~
opposite the first direction, unwinding the first cable from the spool;

~~tracking a distance of the tool from the anchor point by counting fractional~~
~~rotations of the spool as the cable is wound and unwound therefrom; and~~

~~calculating a force response vector based at least on a current position of the~~
attachment point;

calculating an optimization of a function of having at least a first term and a second term, the first term including the calculated force response vector and a calculated tension vector for the first cable, the second term including a function having at least a magnitude of the calculated tension vector for the first cable as an argument thereof, wherein the optimized function is close to or equal to zero; and

selectively applying active tension to the first cable based at least on the calculated tension vector.

limiting tracking errors introduced by changes in effective diameter of the spool as the effective diameter changes in response to the cable being wound and unwound therefrom.

63. (Currently Amended) The method of claim 62 wherein the first cable is one of a plurality of cables having respective first and second ends, the first ends coupled to the tool and the respective second ends coupled to respective ~~anchor points~~ spools, and further comprising:

for each respective cable of the plurality of cables,

winding ~~each of the plurality of cables~~ the respective cable onto a respective spool as the tool is moved ~~closer to the respective anchor point; in a respective first direction.~~

unwinding ~~each of the plurality of cables~~ the respective cable from the respective spool as the tool is moved ~~away from the respective anchor point; in a respective second direction which is opposite the respective first direction.~~

tracking a distance of the tool from each of the respective anchor points respective paid-out cable amount for each respective cable by counting fractional rotations of each of the respective spools; and

limiting tracking errors introduced by changes in an effective diameter of ~~each of the respective spools~~ spool of the respective cable as the effective diameter changes in response to the respective cable being wound and unwound therefrom.

64. (Currently Amended) The method of claim 62 ~~wherein:~~
the number of cables in the plurality of cables is equal to three; and
the respective anchor points are positioned in a triangle that defines ~~wherein the~~
first cable is one of three cables, each cable having a respective first end coupled to the tool and
providing a plane in which the tool has freedom to move, the plane defined by three cable
guides, wherein each respective cable extends from the tool and to a respective one of the three
cable guides.

65. (Currently Amended) The method of claim 62 ~~wherein:~~
the number of cables in the plurality of cables is equal to four; and
the respective anchor points are positioned at respective vertices of a tetrahedron
~~positioned within wherein~~ the first cable is one of four cables, each cable having a respective
first ends coupled to the tool and providing a volume of space in which the tool has freedom to
move defined four cable guides positioned at respective vertices of a tetrahedron, wherein each
respective cable extends from the tool and to a respective one of the four cable guides.

66-67. (Canceled)

68. (Currently Amended) The haptic device of claim ~~67~~ 12, wherein the
~~objective function of the optimization process is~~ mathematical equation includes a sum of (1) the
first term and the second term, wherein the net vector is a vector difference between the
calculated force vector to be applied and a target force vector and the calculated tension vectors,
and (2) a ~~wherein the function of the second term is a multiplicative product derived from a~~
~~plurality of factors, at least one of which is the amount of active tension to be applied by the~~
~~motor of each of the tool translation effector devices that include at least the respective~~
magnitude of each of the calculated tension vector.

69. (Canceled)

70. (Currently Amended) A method for controlling a haptic system, comprising:

~~determining~~calculating a target force vector ~~to be corresponding to an actual force vector~~ applied to the tool;

~~determining~~respective calculating a plurality of target tension vectors, each target tension vector corresponding to an applied tension in a respective cable of a plurality of cables coupled to a tool with respect to the tool;

calculating a target value of a function having at least respective magnitudes of the plurality of target tension vectors as arguments thereof;

adjusting the plurality of target tension vectors based at least on a balance of an equation having at least a first term and a second term, the first term having a net vector with the target force vector and the plurality of target tension vectors as terms thereof, the second term having at least the target value of function as a term thereof; and

~~determining~~ respective tensions ~~to be applied to the plurality of cables to apply an actual force vector to the tool, including balancing (1) a difference between the resulting actual force vector applied to the tool and the target force vector and (2) a magnitude of the tensions to be applied to the cables; and~~

applying the ~~determined tensions~~ target tension vectors to the respective cables to apply~~yield~~ the actual force vector.

71. (Currently Amended) The method of claim 70 wherein ~~the balancing the (1) difference between the actual force vector and the target force vector and (2) the magnitude of the tensions~~ adjusting the plurality of target tension vectors based at least on a balance of an equation having at least a first term and a second term comprises selecting the tensions ~~to be applied to the plurality of cables~~ respective target tension vectors and respective magnitudes thereof such that ~~the difference~~ a summation of the first term and the second term of the balanced equation is close to or equal to ~~a selected fixed value multiplied by the magnitude of the tensions~~ zero.

72. (Canceled)

73. (Previously Presented) The method of claim 71 wherein the selected fixed value is a stability coefficient.

74. (New) The method of claim 71 wherein calculating a target value of a function having at least respective magnitudes of the plurality of target tension vectors as arguments thereof comprises a product of multiplying the respective magnitudes of the respective target tension vectors by a coefficient.

75. (New) The haptic interface device of claim 9 wherein the function of the second term includes a product of squared magnitudes of the respective tension vectors multiplied by a stability coefficient.

76. (New) The haptic interface device claim 12 wherein the function of the second term includes a product of squared magnitudes of the respective calculated tension vectors multiplied by a stability coefficient.

77. (New) The haptic device of claim 12 wherein the user interface tool includes a sensor array configured to detect at least one of roll, pitch, and yaw of the user interface tool.

78. (New) The method of claim 38 wherein the function of the second term comprises a product of squared magnitudes of the respective calculated target tension vectors multiplied by a stability coefficient.

79. (New) The method of claim 62 wherein the function of the second term comprises a product of squared magnitudes of the respective calculated tension vectors multiplied by a stability coefficient.